

RELATIONS BETWEEN THE WEATHER AND THE YIELD OF WHEAT IN THE ARGENTINE REPUBLIC.

By N. A. HESSLING, in charge of Rainfall Section, Argentine Meteorological Office.

[Translated from *Boletín Mensual*, Oficina Meteorológica Argentina, April, 1919.]

Wheat is the most important crop in the Argentine Republic. During the last 10 years the area seeded to this cereal has varied between 6,000,000 and 7,000,000 hectares (1 hectare=2.47 acres); that is about twice the area covered with corn. As the yield of corn is more or less double that of wheat, the production in tons is about the same for the two cereals, although when we count the value of the respective crops, wheat again becomes the more important.

The average yield of wheat in the last 30 years, according to data published in the *Agricultural Statistics*, has been 720 kilograms per hectare, taking the country as a whole. Table 1 gives the yield for each year from 1890 to 1919. The maximum yield was 1,216 kilograms per hectare, obtained in 1893, and the minimum 333 kilograms in 1916. The variations in the yield from year to year, therefore, have been considerable, although not as large as in the case of corn.

TABLE 1.—Yield of wheat in kilograms per hectare in the Argentine Republic.

[By sown area.]

Year.	Yield.	Year.	Yield.	Year.	Yield.
1890.....	703	1900.....	602	1910.....	635
1891.....	742	1901.....	466	1911.....	656
1892.....	966	1902.....	784	1912.....	737
1893.....	1,216	1903.....	817	1913.....	434
1894.....	835	1904.....	837	1914.....	735
1895.....	559	1905.....	647	1915.....	692
1896.....	344	1906.....	746	1916.....	333
1897.....	559	1907.....	909	1917.....	883
1898.....	893	1908.....	701	1918.....	714
1899.....	851	1909.....	611	1919.....	991
Means.....	770	Means.....	710	Means.....	681

Mean yield for 30 years (1890-1919), 720 kilograms per hectare.

TABLE 2.—Mean rainfall (millimeters) in the wheat zone of the Argentine Republic.

Year.	May.	June.	July.	August.	September.	October.	November.	December.
1890.....	26	2	35	25	4	31	83	88
1891.....	51	43	53	64	21	85	67	88
1892.....	11	2	26	56	5	87	87	50
1893.....	45	8	37	16	9	25	57	27
1894.....	46	7	36	20	23	103	95	91
1895.....	35	86	13	39	95	91	96	182
1896.....	51	5	47	16	77	87	128	114
1897.....	50	28	16	23	27	61	75	127
1898.....	27	53	8	19	18	74	80	135
1899.....	45	19	35	49	42	58	70	79
1900.....	79	55	39	72	84	98	83	89
1901.....	40	26	10	22	43	82	87	52
1902.....	82	14	24	2	31	69	86	110
1903.....	31	52	29	38	43	47	94	102
1904.....	7	27	44	33	53	101	132	64
1905.....	50	17	30	19	43	151	64	115
1906.....	26	35	55	47	32	71	64	69
1907.....	17	12	12	35	60	72	76	99
1908.....	68	47	53	11	57	70	109	63
1909.....	12	16	33	27	113	72	101	75
1910.....	29	8	11	13	48	63	54	34
1911.....	84	89	53	38	34	124	109	187
1912.....	62	47	25	55	34	104	122	127
1913.....	70	17	13	92	55	68	113	81
1914.....	103	35	69	55	40	103	134	159
1915.....	29	4	7	15	43	80	73	108
1916.....	28	6	4	22	12	17	37	90
1917.....	6	37	60	7	55	36	31	52
1918.....	36	46	5	10	84	92	148	91
1919.....	100	63	79	10	90	93	109	150
Averages.....	45	30	32	32	46	77	90	97

In the yield of corn, it has been shown that the principal factor is the rainfall, and the next the temperature. The present study is an attempt to determine the effect of these factors on the yield of wheat.

Effect of the rainfall variations on the yield of wheat.—The rains that might be expected to affect the yield of wheat in this country, seeing that it is sown in the months of May to August, the harvest beginning in November or December, would be those that fall from June to November. In Table 2 are given the average amounts of rainfall over the wheat zone of the Republic, that is, over the Provinces of Buenos Aires, Entre Rios, Santa Fé, Cordoba, and Pampa Central Territory. Although the yield data of Table 1 really refer to the whole country, what is produced outside of this zone forms only a small portion of the whole.

A comparison of these data with those of the yield in Table 1 shows that between the two there is very little relation. The six years of largest yield were 1893, 1892, 1919, 1907, 1898, and 1917. In five of these the total rainfall of June to November was below the normal, and in the other, 1919, it was excessive. The yields were lowest in 1916, 1896, 1913, 1901, 1895, and 1897. Of these, 1916 was the driest of all, in 1897 and 1901 the rain was below normal, while in the remaining three it was above normal.

TABLE 3.—Yield of wheat (kilograms per hectare) in the Argentine Republic.

[Averages according to rainfall in the months June to November.]

	Millimeters of rain.							
	Less than 100	100-150	150-200	200-250	250-300	300-350	350-400	400-450
Number of cases....	1	0	3	4	6	6	5	5
Average yield.....	333	.....	861	724	819	728	823	729
Maximum yield.....	.....	.....	1,216	883	996	817	837	991
Minimum yield.....	.....	.....	635	599	466	647	344	559

Grouping the yield data according to the rainfall from June to November, and taking averages of the yield for every 50 millimeters of rainfall, as shown in Table 3, it will be seen that the maximum yield corresponds to rains of 150 to 200 mm. In the first group, corresponding to rains of less than 100 mm., there occurs only one case, that of the year 1916. There are no cases of rainfall between 100 and 150 mm., which shows the exceptional character of the year 1916, and the average of the next group is the maximum, from which it seemingly might be inferred that the only year in which the wheat suffered from want of rain was 1916. But perhaps it is not correct to consider the yield in relation to the total rainfall of the six months. The rain in certain months is no doubt more effective than in others, and besides, in six months there may occur periods of drought that might affect the wheat, although the total rainfall of the six months be sufficient. For this reason the yield data have also been analyzed with respect to the rainfall of the four months July to October and the three-month periods June-August and September-November.

TABLE 4 — *Yield of wheat (kilograms per hectare) in the Argentine Republic.*

[Averages according to rainfall in the months July-October, June-August, and September-November.]

Periods.	Millimeters of rain.						
	Less than 50.	50-75	75-100	100-150	150-200	200-250	More than 250.
July-October:							
Number of cases.....	0	1	2	6	8	10	3
Average yield.....		333	990	738	786	631	776
Maximum yield.....			1,216	893	980	837	991
Minimum yield.....			703	559	466	344	602
June-August:							
Number of cases.....	4	9	4	8	5		
Average yield.....	606	710	846	750	745		
Maximum yield.....	764	1,216	990	851	991		
Minimum yield.....	333	344	611	434	602		
September-November:							
Number of cases.....	0	1	0	3	10	5	11
Average yield.....		333		854	770	668	676
Maximum yield.....				1,216	990	909	876
Minimum yield.....				703	559	434	602

These means show a similar distribution to those of June to November; that is, the maximum yield is obtained on the average with rains, that differ little from the minimum observed. But in whichever way the averages are formed it must be admitted that they do not show any marked correlation between rainfall and yield. If this correlation existed there would be some symmetry in the averages; that is to say, after rising to a maximum they would gradually diminish, forming when expressed graphically a curve more or less pronounced, but without the waves or irregularities shown by these. Both by this lack of symmetry, as well as by the large differences between maxima and minima in each group, it may be inferred that the rainfall is not the principal factor in the yield of wheat, at least when considering the yield of the country as a whole, with the mean rainfall in the corresponding zone.

But perhaps this lack of correlation is due to the fact that the area considered is too large. The area where wheat is cultivated is very extensive, and in some years the rainfall may be insufficient in some parts of this area and excessive in others. The best would no doubt be the data for departments (counties), because even the provinces, especially Buenos Aires, still comprise areas too large to refer their rainfall to an average quantity. But it seems there are no data available by departments, and the only more detailed data I have been able to obtain are those of the Provinces of Buenos Aires, Entre Rios, Santa Fé, Córdoba, and the Territory of Pampa Central during the years 1908-1918, which are given in Table 5.

TABLE 5.—*Yield of wheat (kilograms per hectare), by Provinces, 1908-1918.*

[By harvested area.]

Year.	Buenos Aires.	Entre Rios.	Santa Fé.	Córdoba.	Pampa Central.
1908.....	792	739	714	678	350
1909.....	723	680	501	650	821
1910.....	758	632	556	634	756
1911.....	822	744	672	610	662
1912.....	836	597	687	750	731
1913.....	536	422	440	441	554
1914.....	844	544	671	806	810
1915.....	852	909	799	605	595
1916.....	551	460	467	353	216
1917.....	804	1,224	1,068	1,070	745
1918.....	969	572	860	642	643
Averages.....	773	684	749	658	626

These data differ from those of Table 1 in having been taken from the area harvested instead of the sown area; that is, in this case the total failures have been eliminated. The true yield should of course be computed from the sown area. There might, for instance, be cases of total loss through drought, in which case the yield computed from the harvested area would be too large. On the other hand, in some cases this method might be more advantageous, as when the failure is due to other causes than those the subject of investigation, for instance in this case, if they were due to frost, hailstorms, or causes not meteorological.

The data for 11 years are, of course, insufficient to determine the correlation between rainfall and yield for each Province. The effect of the rainfall is not necessarily the same in different regions. It no doubt varies with the temperature, the character of the soil, the topography, and other factors. But to determine these differences by statistical methods would require much more data than we possess. However, utilizing the existing data as far as possible, and disregarding, for the present, the differences of correlation that may exist in different regions, we will see, if with these data it is possible to determine the effect of the rainfall with more precision than with those from the country as a whole.

With this object in view, the averages of Table 6 have been computed, which have been formed, grouping the data from any Province according to the mean rainfall in the respective Province.

TABLE 6.—*Yield of wheat (kilograms per hectare) in the Provinces Buenos Aires, Entre Rios, Santa Fé, Córdoba, and Territory of Pampa Central.*

[Averages according to rainfall, June-November, June-August, and September-November.]

June-November.	Millimeters of rain.										
	25-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	Over 500
Number of cases...	1	2	4	7	8	7	7	6	4	7	2
Average yield.....	353	612	530	690	846	796	620	658	749	701	558
Maximum yield.....		756	596	1,098	1,224	852	836	806	989	866	572
Minimum yield.....		467	216	551	605	678	440	536	597	422	544

June-August.	Millimeters of rain.							
	Less than 10	10-25	25-50	50-100	100-150	150-200	200-250	250-300
Number of cases...	5	6	9	16	12	3	3	1
Average yield.....	585	588	671	751	704	708	631	544
Maximum yield.....	662	821	822	1,070	1,224	844	687	
Minimum yield.....	467	350	460	216	422	536	597	

September-November.	Millimeters of rain.								
	25-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450
Number of cases....	1	5	11	6	11	13	5	2	1
Average yield.....	353	450	797	687	674	720	650	751	572
Maximum yield.....		756	1,224	909	852	989	844	860	
Minimum yield.....		216	561	556	440	501	422	642	

On the whole, these averages are similar to the first ones, and they show, that the most favorable condition for the wheat is, when it rains in the three winter months 50 to 100 mm., and in September to November 100 to 150 mm. If it rains less than these quantities, it is insufficient, and if it rains more, the yield in general decreases. This decrease, however, is not at all propor-

tional to the increased rainfall, there being cases of high yield with abundant rains, and it does not seem that the decrease of the yield after the maximum can be attributed directly to the excess of rain. It seems rather that the rainfall, as long as it is sufficient, or say about 100 to 150 mm. in three months, does not affect the yield greatly, and that the decrease of the yield with larger rainfalls is caused by other factors.

So far we have considered the yield with respect to the winter and spring rains independently from each other. But it seems probable, that the effect of the spring rains will vary according to the rains fallen before in the winter, and this is really what is shown by Table 7.

TABLE 7.—Yield of wheat analyzed according to the combined rainfall of winter and spring.

[Rainfall in millimeters.]

	Rainfall of September to November.						
	Less than 50.	50-100	100-150	150-200	200-250	250-300	300-350
Rainfall, June-August, less than 25:							
Number of cases.....	1	3	2	2	1	2	0
Average yield (kilograms per hectare).....	353	524	628	598	605	736	.....
Rainfall, June-August, 25-50:							
Number of cases.....	0	1	1	1	4	0	2
Average yield (kilograms per hectare).....	.....	460	554	632	777	.....	642
Rainfall, June-August, 50-75:							
Number of cases.....	0	0	3	1	1	2	0
Average yield (kilograms per hectare).....	.....	.....	676	909	852	612	.....
Rainfall, June-August, 75-100:							
Number of cases.....	0	1	3	1	1	2	1
Average yield (kilograms per hectare).....	.....	216	981	792	750	723	890
Rainfall, June-August, over 100:							
Number of cases.....	0	0	2	1	4	7	5
Average yield (kilograms per hectare).....	.....	.....	991	597	524	746	632

The averages of this table have been computed, first grouping all the cases according to the rainfall of June to August. Then in each of these groups the yield has been analyzed with regard to the rainfall of September to November. Although the data are certainly very scanty to be treated in this way, still the position of the maximum in each primary group clearly shows, that the need of rain in the spring decreases in proportion as the winter rains have been larger. The table also shows, how important are the winter rains for the wheat yield, the maximum yields with winter rains of less than 50 mm. being much smaller than maxima and even than the yield in general, when the winter rainfall has been greater than 50 mm.

When the rainfall of the three winter months has been less than 25 mm., the maximum yield is obtained with the highest amount of rain observed in spring. That is, if there has been drought in winter, in the spring the rainfall will never be excessive, or at least it has not been so in the 11 years covered by this study. As the winter rains increase, the quantity of rain necessary in spring to obtain the maximum yield decreases until with winter rains of more than 100 mm., the maximum yield corresponds to the lowest amounts of rain in the spring. Of course it can not be inferred, that if in this case the spring rains had been still less, the yields would be larger, because however abundant the winter rains may be, they can not altogether replace the spring rains. It is though, fairly certain, that if it has rained enough

in the winter, the spring rains will also be sufficient, because the severe droughts in spring are always preceded by dry winters.

TABLE 8.—Yield of wheat (kilograms per hectare) in the Provinces Buenos Aires, Entre Rios, Córdoba, Santa Fe, and Territory of Pampa Central.

[Averages according to bimonthly rainfall.]

Periods.	Millimeters of rainfall.									
	Less than 10	10-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	Over 200
May-June:										
Number of cases.....	3	13	12	7	5	5	6	1	1	2
Average yield.....	593	642	661	728	766	746	719	671	572	570
June-July:										
Number of cases.....	15	7	10	5	10	4	3	0	1	0
Average yield.....	538	607	712	736	824	866	674	.....	544	.....
July-August:										
Number of cases.....	9	8	13	8	6	4	3	3	1	0
Average yield.....	649	577	766	757	673	660	562	653	544	.....
August-September:										
Number of cases.....	0	4	5	15	16	6	4	2	1	2
Average yield.....	.....	512	686	747	724	664	648	540	680	497
September-October:										
Number of cases.....	0	2	3	3	11	8	9	11	7	1
Average yield.....	.....	410	477	490	806	641	631	738	729	572
October-November:										
Number of cases.....	0	0	3	9	5	3	1	9	10	15
Average yield.....	.....	.....	598	641	823	594	536	693	702	673

Table 8 has been made with the object of showing more exactly at what time the rains are most necessary for the wheat. For this table the yield data have been arranged according to the bimonthly rainfall, beginning with May to June. Approximately the effect of the rains may be judged by the difference between the groups of maximum and minimum yield. The difference is largest for the months of September to October, in which it amounts to 396 kilograms per hectare. June, July come next with 328 kilograms, which confirms what has been noticed before about the importance of the winter rains.

Apparently in August the rains are less necessary, possibly because at this time the plant may require more sunshine, and the amount of sunshine will naturally, in general, vary inversely to the rainfall.

Summing up the results, it may be said, that the rainfall in the Republic, excepting very rarely, is sufficient to obtain a good yield of wheat. Taking the country as a whole, the only case of real drought in the last 30 years was the year 1916. Considering the data by Provinces, there are more cases of diminished yield by that cause, that is by partial droughts, felt in one or in some of the Provinces. Specially in the winter and in the interior of the country, as in Córdoba and the Pampa, where the winter rainfall is normally very scarce, the want of rain is felt more frequently.

The most favorable quantity, that is with which the highest yields have been obtained, is about 100 mm. in June and July and another 100 mm. in September to October. The normal rainfall in the winter is less than this in Córdoba, the Pampa, and western Buenos Aires, while in spring it is more throughout the wheat region.

These results, however, correspond only to averages, but the correlation between rainfall and yield of wheat is very vague, and in individual cases the variations of the yield with similar rainfall are so large that it would be quite useless to attempt forecasting the yield by the rainfall alone.

Possibly the results would have been more definite if more detailed data had been available as by departments or smaller regions. Besides to determine with more exactness the real effect of the rain, it would be necessary to have data respecting the time of sowing, which varies

somewhat in different Provinces and from year to year, because naturally the critical time of growth will differ according to the time of sowing.

EFFECT OF THE TEMPERATURE VARIATIONS ON THE YIELD OF WHEAT.

Data covering the period since 1890 are not available from a large enough number of stations to compute the real average temperature over the wheat zone. But the variations from the normal can be computed by a much smaller number of stations, because the temperature variations are nearly the same over this entire region. For Table 9 only the data from three stations have been used, Buenos Aires, Córdoba, and Bahia Blanca; the first two are the only ones that cover the entire period, and the observations at Bahia Blanca begin in 1896. First the differences from the normal have been computed for each station, and then the average taken of these differences.

The mean of these three stations could not be considered as representing the temperature in the wheat region, and besides the inclusion of Bahia Blanca in 1896 would introduce a change in the normal. However, the variations are nearly always in the same sense at the three stations, and when they are large at one, they are also large at the other two, so that the mean of the three can quite well represent the variations of the temperature over all this region.

TABLE 9.—*Deviations from normal temperature in the wheat zone of the Argentine Republic.*

Years.	June.	July.	August.	September.	October.	November.
	°C.	°C.	°C.	°C.	°C.	°C.
1890.....	-1.2	0.2	-1.1	-1.4	0.7	1.8
1891.....	.6	-.9	.8	.2	0	.2
1892.....	-2.0	.5	-1.1	-.7	.3	-.6
1893.....	-1.9	.8	-1.2	-2.0	-2.5	-.4
1894.....	-1.4	-.8	-.4	-.8	-1.3	0
1895.....	2.8	1.2	1.4	.6	-.7	-.3
1896.....	-1.2	2.7	3.8	2.1	1.2	1.0
1897.....	.3	-2.1	-.8	-.4	1.6	.7
1898.....	.6	-1.9	-2.0	-.9	-1.8	-1.7
1899.....	-2.1	3.0	.8	-.7	-.7	-.9
1900.....	.6	1.6	0	-.7	-.1	-.9
1901.....	3.0	-.4	.2	2.0	2.1	.7
1902.....	1.3	-.9	-2.0	-.3	.5	.1
1903.....	.1	0	0	2.0	-.6	-.3
1904.....	.2	1.3	-.5	.8	-.2	-1.2
1905.....	.2	-1.8	.5	.4	-.3	-.1
1906.....	2.2	-.1	.7	-.5	1.2	.1
1907.....	-.9	-.3	-1.2	-1.4	-.9	-.1
1908.....	1.3	-.2	-1.1	.1	-.3	0
1909.....	-1.1	-.3	2.2	.8	-.5	-1.8
1910.....	1.0	-1.1	.9	-.2	1.2	-.9
1911.....	-1.1	0	-1.3	-2.3	-1.0	-.2
1912.....	.4	-1.3	-1.2	.6	.8	-.3
1913.....	1.2	3.1	1.0	1.0	-.7	1.6
1914.....	2.3	1.8	.1	-.6	-.2	-2.1
1915.....	-2.7	-.6	1.6	-.3	.6	1.3
1916.....	-3.8	-2.4	.3	1.5	2.0	1.1
1917.....	.9	-.9	-.7	.4	0	.8
1918.....	-.7	-.1	-.5	-1.3	-.3	-.1
1919.....	-.1	-.2	-.7	-1.3	-.7	-.9

If these data are compared with the yield figures, at once a much closer correlation is brought into evidence than in the case of the rainfall. In nearly all the years with large yield the deviations in the spring months are negative, that is the temperature has been below normal, and in those with small yield they are positive or above normal. Of course there are some exceptions, but the only really notable exception is 1911, when the spring was cold, and notwithstanding this, the yield was below the average. It is known though, that in this year the harvest, which at first was very promising, was spoilt by the heavy rains, that fell in December. In a large part

of the zone over 300 mm. fell in that month, the wheat fields in many places being flooded at harvest time.

In general the yield seems to be more or less inversely proportional to the temperature, which fact allows the relation between temperature and yield to be expressed by the correlation coefficient, a simple and practical method, but which could not be employed in the case of the rainfall, because between the rainfall and the yield there is no linear correlation.

Computing the correlation coefficient, the yield and bimonthly temperatures, beginning with June-July, we get:

June-July.....	-.10
July-August.....	-.32
August-September.....	-.60
September-October.....	-.75
October-November.....	-.67

The temperatures of June and July apparently have no influence but in August their effect is already well apparent, coming to their maximum in September and October. Combining several months, the maximum correlation is -0.81 , for the four months August to November and taking out the year 1911, in which the low yield was due to the heavy rains at harvest time, the coefficient becomes -0.86 .

According to W. H. Dines (*Meteorological Magazine*, London, February, 1921) the effect of one variable over another is to be measured by the square of the correlation coefficient. The square of 0.86 is 0.74 , so therefore 74 per cent of the variations in the wheat yield are due to variations in the temperature in the months of August to November.

There have been cold and dry springs, like 1893 and 1898, cold and wet like 1919, and in nearly every case, when the temperature has been markedly below the normal, the yield of wheat has been high. Likewise there are cases of a warm and dry spring, like 1910 and 1916, and warm and wet, like 1896 and 1913, and in all of these cases the yield of wheat has been low. Consequently there is no doubt that the temperature is a much more important factor than the rainfall in determining the yield of wheat.

It is of interest in this connection to consider the relation between the temperature and rainfall. When studying the effect of these elements on the yield of corn, it was found that in summer the droughts are generally accompanied by high temperatures, the explanation evidently being that when the air is dry, the solar rays pass more easily through to the earth's surface, while when the air contains more moisture, a greater proportion of heat is absorbed by the upper layers of the atmosphere. In winter the opposite is the case, the dry winters being usually cold, and the wet ones warm, because the terrestrial radiation at this season being greater than the solar, the drier the air, the greater will be the loss of heat. In the intermediate season of spring, the incoming and the outgoing radiation being balanced, the variation of each element is less dependent on the other.

The variations of temperature, contrary to what is the case with the rainfall, being nearly always general in character, their effects on the wheat will be better studied on a large zone, because in that way the local variations are in a great part eliminated. In Table 5 it can be seen, that in some years the yield varies considerably from one Province to another. As the variations of temperature are nearly alike in all the provinces, these differences of yield must be ascribed to more local factors, among which may be included the rainfall. It

is to be expected, therefore, that the correlation coefficient between the provincial yields and the corresponding temperatures will be smaller than when the yield in the whole country is considered. However, it will be of interest to see the variation of the correlation, month by month, in each Province, although the period of 11 years is too short to attach much value to the correlation coefficients. These are given in Table 10.

TABLE 10.—Correlation coefficients between the monthly temperatures of each Province and the corresponding wheat yield.

	June.	July.	August.	September.	October.	November.
Buenos Aires.....	0.19	-0.02	-0.27	-0.72	-0.43	-0.12
Entre Rios.....	.02	-.29	-.39	-.26	-.21	.10
Santa Fé.....	.14	-.21	-.42	-.33	-.23	.18
Córdoba.....	.49	-.27	-.45	-.15	-.42	-.23
Pampa Central.....	.50	.04	.18	-.36	-.58	-.48

In the more northern Provinces of Entre Rios, Santa Fé, and Córdoba, where the wheat is generally sown and harvested earlier, the temperatures of August have the greatest effect; in Buenos Aires it is those of September, and in the Pampa those of October.

In June, the coefficients are positive, but only in Córdoba and the Pampa are they large enough to be significant, showing that in the interior of the country an increase of temperature in June is beneficial. The reason probably is that the temperature is higher in the wet winters, and the winter rain in these regions, where it generally is insufficient, is a factor of some importance for the wheat yield.

POSSIBILITY OF COMPUTING THE YIELD BY MEANS OF THE METEOROLOGICAL ELEMENTS.

The principal practical application of these relations is of course, their utilization as an aid in forecasting the crop. The correlation between the temperature and the yield of wheat is so close that with this element alone it is possible to forecast with a fair approximation the resulting crop. As the yield is more or less inversely proportional to the mean temperature of the months August to November, a constant would have to be found, that, multiplied by the temperature or by the departures from the normal, would give the yield. This constant, called generally "regression factor," can be computed by the

formula $b = \frac{\sum xy}{\sum x^2}$, in which b is the regression factor, x

the causative variable, in this case the temperature, and y the resulting variable, in this case the yield.

For the whole country b results = -208 for the months of August to November, that is, for each degree, that the mean temperature of those months is higher or lower than the normal, the yield of wheat will diminish or increase respectively 208 kilograms per hectare.

In Table 11 are given the yields for each year from 1890 to 1919, computed by means of this coefficient and the deviations of the temperature from the normal, the differences between these computed yields and the actual ones being also given.

TABLE 11.—Yield of wheat (kilograms per hectare) computed by means of the temperature of August to November and difference between this and the actual yield.

Year.	Computed yield.	Difference with obtained yield.	Year.	Computed yield.	Difference with obtained yield.
1890.....	720	-17	1905.....	699	-52
1891.....	658	+84	1906.....	637	+109
1892.....	824	+172	1907.....	907	+2
1893.....	1,032	+184	1908.....	762	-61
1894.....	845	-10	1909.....	678	-67
1895.....	678	-19	1910.....	534	+81
1896.....	304	+40	1911.....	970	-314
1897.....	658	-99	1912.....	720	+17
1898.....	1,053	-160	1913.....	491	-57
1899.....	803	+48	1914.....	866	-131
1900.....	637	-35	1915.....	554	+138
1901.....	470	-4	1916.....	470	-137
1902.....	803	-39	1917.....	699	-184
1903.....	658	+159	1918.....	762	-48
1904.....	782	+55	1919.....	907	+84

In Figure 1 the computed yields are compared graphically with the yields obtained. The resemblance of the two curves is remarkable, considering that only one element has been used in the computations, while the yield naturally results from various factors.

The differences between the computed and the actual yields can be considered as what is left of the variations of the yield, when the temperature effect has been deducted, and consequently it might be expected that these residuals would show better than the total variations, the effect of less active factors, like the rainfall.

Analyzing these differences according to the rainfall, it is seen that in 1916 the difference is negative, which is doubtless due to the drought of that year. On the average, the differences are also negative, when the rain has been excessive, but the year 1919 is an exception. With rainfall nearly normal, the differences on the average are positive, but in this case the extreme values vary so much, that in general it does not seem that the results would gain much in accuracy by including the rainfall as a factor in the computations.

The appraisal of this factor is, as has been seen, rather difficult. A relatively small quantity may be sufficient, if it is well distributed over the growing period, while a larger quantity may be insufficient, if badly distributed. For instance, what saved the crop in 1893, was undoubtedly the fair amount of rain that fell in July of that year, which allowed the wheat to withstand the relative drought of the next three months (see Table 2); without that rain, or if it had fallen later, say in September, it is very probable that the crop of that year, instead of being the best of these 30 years, would have been much below the normal, notwithstanding the favorable temperature. In 1898 the temperature was also favorable, but the yield, although above normal, does not come up to the value computed by the temperature. In this year there was also a drought of three months, but in this case it started in July, that is a month earlier than in 1893, which seems to be the principal difference between the two years.

Some of the negative differences, besides 1911, already mentioned, may be due to excessive rains during the harvest season, a factor that is of course actually impossible to foretell. This seems notably to be the case in

1895 and 1914. Another cause of diminished yield might be the late frosts. The most notable year in this respect was 1908, in which occurred a sharp frost in the middle of October; however, in this year the difference, although negative, is not one of the largest.

As the rainfall might possibly have an indirect effect, modifying that of the temperature, and to try if, taking into account this modification, it would be possible to make the computations more accurate, the data have been divided into three groups according to the rainfall. For this purpose the rainfall from July to October was used, although the result would obviously have been about the same if some other period, like June to November had been used. The first group comprises those cases, in which the rainfall of these four months was less than 150 millimeters, the second, the rainfall of 150 to 200 mm. and the third, when it was above 200 mm. Then the correlation between the yield and the temperature of August to November has been computed for each group. The coefficients are respectively -0.83 , -0.85 and -0.89 , and the regression coefficients -204 , -205 and -206 (excluding the year 1911).

The differences of the regression coefficients are obviously too small to modify appreciably the computations, but the correlation coefficient increases somewhat with the rainfall, that is, when the rain has been abundant, the yield computed by the temperature will be more nearly accurate, while with smaller rainfall, the yield is more likely to be affected by other factors not related to the temperature.

The temperature, as has been seen, although it does not permit us to compute the yield with exactness, can serve as a very useful auxiliary factor to forecast the crops. The computations here given have been made with the temperatures of August to November, that is, they can be made at the beginning of December. However, they could be made with almost the same accuracy with the temperatures of August to October, when they could be made at the beginning of November. The correlation coefficient in this case is -0.85 and the regression factor -186 . Computing the yield with this latter coefficient and the temperature deviations of August to October, the mean of the differences between computed and obtained yield, without distinction of sign, is 91, while in the first case it is 83, excluding in both cases the year 1911.

THE SPECIFIC WEIGHT OF THE WHEAT.

Besides the yield, the specific weight of the wheat is also of interest. Like the first, it varies from year to year, and in different localities, variations that no doubt also are related to meteorological phenomena. For the specific weight of the wheat there are data published in the *Agricultural Statistics* since 1908 from each department.

Analyzing these data with respect to the rain and temperature does not reveal any relation with these elements, excepting that the greater specific weight corresponds in general to the scantiest rainfall. It does not seem likely, that the rainfall has in reality the effect of diminishing the specific weight, but this is more probably an indirect effect, and related really to the sunshine, which in general varies more or less inversely with the rainfall.

There are no sunshine data, except from very few stations, but instead the data of cloudiness can be used, which is more or less inversely proportional to the sunshine. Grouping the data of specific weight from those

departments, where a meteorological station exists, according to the cloudiness observed, we get the averages given in Table 12.

TABLE 12.—Specific weight of wheat (kilograms per hectoliter).

[Averages according to grades of cloudiness.]

PROVINCE OF BUENOS AIRES.

	Grades of cloudiness.						
	1	2	3	4	5	6	7
June.....	64.0	71.6	75.4	77.6	76.5	74.3	.....
July.....	78.0	77.2	77.3	76.2	75.9	72.8	.....
August.....	77.1	76.1	76.1	76.7	75.5	74.8	.....
September.....	77.6	77.5	76.6	76.0	75.2	74.5	.....
October.....	.....	78.8	76.3	76.5	74.2	78.6	77.3
November.....	.....	76.3	76.8	75.3	75.1	75.5	.....
December.....	77.0	76.5	76.6	77.0	70.4	74.9	.....

SANTA FÉ AND CÓRDOBA.

	Grades of cloudiness.						
	1	2	3	4	5	6	7
June.....	77.9	77.3	76.5	76.3	77.2	76.3	.....
July.....	79.6	75.9	77.1	76.9	76.5	77.0	74.8
August.....	.....	78.1	76.3	75.8	77.5	76.3	.....
September.....	81.5	77.6	77.1	76.1	76.7	75.6	.....
October.....	81.5	79.0	77.2	76.9	75.3	74.1	.....
November.....	79.7	78.5	77.8	76.6	73.2	76.5	.....
December.....	78.1	79.6	77.3	75.9	75.6	71.9	.....

As can be seen the maximum specific weights correspond to the minimum of cloudiness and in general also the minimum weights to the maximum of cloudiness. The diminution is in general progressive as cloudiness increases, so it may be concluded that the specific weight varies inversely with the cloudiness or in direct ratio to the sunshine.

The individual data certainly do not always show such a close relation as these averages, but these show

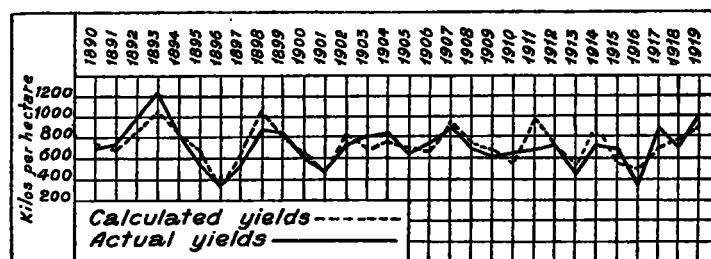


FIG. 1.—Graphical comparison between yields calculated by the temperature of August-November and actual yields. (Dotted line—calculated yields; solid line—actual yields.)

that the sunshine is the principal factor in determining the specific weight.

The averages have been computed separately for the Province of Buenos Aires and for Córdoba and Santa Fé, the data from Entre Rios and the Pampa being too scanty to use. The two series generally agree, but the differences between maximum and minimum are larger in Córdoba and Santa Fé.

If we measure the relative effect of the sunshine by the difference between maximum and minimum weight, the month in which this element is most important seems to be December, that is when the grain is ripening. It also seems to be important in July and in October.

The result would probably have been better with the sunshine data, because the cloudiness only approximately

represents the former. Besides the data of cloudiness on account of the manner in which this element is observed is subject to variations due to the personal criterion of the observers, and even the international conventions are not yet agreed on some points in this respect. For instance, when the sky is covered with cirro-stratus it is a doubtful point whether the observer should put 10 (overcast), seeing that these clouds let through the greater part of the sunshine.

As the sunshine has this effect on the specific weight, it might be asked if it has not also an effect on the yield. However, as the cloudiness is closely related to the rainfall it would be difficult, especially with the scanty material at hand, to separate the effect of each of these elements. It is possible, though, that the fact of the maximum yields having been obtained with rainfalls near the minimum is explained, because in these cases the plants have received more sunshine than when the rains have been more abundant.

SECULAR VARIATION OF THE YIELD.

The decennial means of the yield (Table 1) show a constant decrease in the last 30 years. It would be of interest to try and find out the causes of this diminution, and especially in connection with this study, if any change in the climate may be responsible for it.

In a study published in the *Monthly Bulletin* of the Argentine Meteorological Office corresponding to August, 1918, on the periods of drought and excessive rains, it was shown that the rainy periods had increased in the Republic in the last 30 years, and in the Province of Buenos Aires, excepting a relative diminution in 1890-1899, they have been constantly increasing since 1860. Notwithstanding this increase of the rainy periods, in the last years have also occurred periods of intense drought, so it seems that the climate has become more extreme, or the variations above and below normal are greater.

These changes in the rainfall may doubtless have some influence on the yield of wheat, but as seen from the foregoing for this cereal the variations of temperature are more important than those of the rainfall.

Taking decennial means of the computed yields (Table 11) we get the following values:

	Kilograms per hectare.
1890-1899.....	757
1900-1909.....	703
1910-1919.....	699

It is seen that these also show a decrease, and as they are computed by means of the temperature, this shows that the average temperature has also changed, or at least the temperature of August to November has increased. We do not know, however, if this variation or that of the rainfall is a real change of climate, that is if it is permanent or if it results from some periodicity, and later that we will get back to the former condition.

The decrease in these computed averages is not as great as that observed according to Table 1. We may conclude therefore that the increase of temperature in spring is responsible for part of the diminution, but not for all. The change in the rainfall may in some part be to blame, but it is probable there are also other causes. One of these is doubtless the gradual extension of the cultivated area toward the west, where the winter rainfall often is insufficient. A proof of this is the fact that the average yield in Córdoba and the Pampa, where wheat growing on a large scale is relatively recent, is less than in Buenos Aires, Entre Ríos, and Santa Fé. (See Table 5.)

In other countries the yield generally shows an increase, ascribed to improved methods of cultivation, and if in our country the application of scientific methods were more general, this factor would doubtless counteract those that tend to diminish the yield, and here also the yield would increase instead of decrease.

THE RAINFALL OF VENEZUELA.

By A. J. HENRY.

[Weather Bureau, Washington, D. C., July, 1922.]

The editor has received from Señor Ernesto Sifontes, Venezuelan Meteorological Service, rainfall statistics for 1919-1921 for several stations in that country. It is possible now to bring up to date the record of rainfall for Caracas, originally published in 1911,¹ for each month of the period January, 1891, to December, 1910, and to complete the records for four other stations. The geographical coordinates of all the stations are given in the table next below and the monthly rainfall, in millimeters, is given in Table No. 2 following.

TABLE 1.—Rainfall stations in Venezuela^a—Geographical coordinates, etc.

Stations.	Lat. N.	Long. W.	Eleva- tion. Meters.	Length of record.	
				Years.	Months.
Caracas.....	10 30	66 56	1,042	31	0
Mérida.....	8 36	71 9	1,641	6	8
Ciudad Bolívar.....	8 9	63 33	26	5	3
Calabozo.....	9 40	67 40	100	3	0
Maracaibo.....	10 35	71 45	6	3	0

^a See C. E. P. Brooks in *Quart. Jour. Roy. Met. Soc.*, 48:71; also G. Hellmann in *Mét. Zeit.*, December, 1921, pp. 375-376.

¹ Ugeto, Luis: *Revista Técnica Del Ministerio De Obras Públicas*, 1911, p. 299.

TABLE 2.—Rainfall (in millimeters) at the stations named.

CARACAS.												
Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1911.....	1.5	25.5	6.4	40.0	93.0	152.8	153.9	174.8	44.4	61.3	85.5	39.1
1912.....	1.8	0	0	3.2	26.9	111.2	139.6	109.8	86.5	44.9	81.0	31.2
1913.....	44.9	0.8	13.6	0	53.6	78.3	63.3	90.3	113.6	73.5	87.9	44.5
1914.....	0	0	1.0	59.0	80.8	13.1	34.5	60.0	43.3	72.6	4.7	24.7
1915.....	19.5	48.1	0	123.5	52.7	129.4	77.0	118.2	110.5	120.1	23.5	5.6
1916.....	11.6	33.7	13.9	3.3	44.1	80.5	126.8	168.9	187.8	58.5	145.7	42.0
1917.....	15.5	14.7	6.3	52.4	34.3	192.6	155.1	77.6	90.2	60.6	29.3	101.9
1918.....	13.7	14.2	12.8	29.7	101.2	124.5	139.6	125.1	33.3	106.8	45.9	10.7
1919.....	0	0.3	28.2	113.0	32.1	122.8	63.9	102.5	108.1	95.9	123.1	4.7
1920.....	2.2	1.3	6.0	0	92.4	141.6	98.5	79.6	29.5	43.9	78.5	16.3
1921.....	25.1	0.3	33.5	16.9	59.1	230.2	95.1	147.9	151.6	141.8	146.7	90.7
Means.....	21.7	9.7	16.8	42.8	71.0	108.5	111.6	108.6	91.8	96.2	84.2	45.8
MERIDA.												
1915.....	104.8	74.5	131.3	130.7	271.0	230.6	183.3	126.2	182.6	132.4	224.3	9.4
1916.....	48.0	40.6	39.7	270.3	409.6	186.7	157.5	179.3	172.2	278.0	240.6	118.4
1917.....	48.0	40.6	71.1	141.5	445.6	185.8	105.7	84.5	133.1	240.3	278.6	43.2
1918.....	34.3	3.9	54.0	287.2	351.4	215.8	71.6	265.4	177.2	280.9	302.3	147.0
1919.....	67.7	46.8	88.3	100.8	255.0	144.2	74.8	93.7	164.2	157.1	52.7	37.3
1920.....	154.6	33.2	107.4	160.2	378.8	88.9	116.2	145.6	122.2	333.8	214.4	68.3
1921.....	154.6	33.2	107.4	160.2	378.8	88.9	116.2	145.6	122.2	333.8	214.4	68.3
Means.....	80.9	43.4	97.5	181.8	315.0	183.9	113.3	162.0	154.9	267.8	212.6	68.1

^a From the full record of 31 years, 1891-1921.